High Optical Efficiency of ZnO Nanoparticles

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Abstract: We develop optically efficient photocatalytic ZnO nanoparticles that we chemically embed and well disperse into host PVAc thin films and experimentally demonstrate the highest optical efficiency of ~70% in ZnO nanoparticle films, with increasing optical spectral efficiency as the excitation wavelength is swept from 370 nm to 290 nm.

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Nanostructured metal-oxide semiconductors find interesting applications in nanophotonics [1-5]. They exhibit peculiar optoelectronic and photocatalytic properties that make them attractive, for example, for optical decontamination of surfaces, air, and water. For such environmental purposes, we develop photocatalytic ZnO nanoparticles integrated in resin and study their optical spectral efficiency between 290 nm and 370 nm. We experimentally achieve very high optical efficiencies up to 70% in ZnO nanoparticle films for the first time.

In photocatalytic processes, semiconductors such as TiO_2, ZnO, CdS, and ZnS are optically activated in ultraviolet (UV) radiation [1, 2]. TiO_2 in the anatase form is the most common one. However, ZnO (3.2 eV) is a better alternative to TiO_2 as far as its bandgap energy is concerned, although it is less commonly used. ZnO is the last member of the 3d metal-oxide series, with Zn completely filling its 3d orbitals ($3d^{10}$). ZnO's conduction band has s-p hybridized orbitals while its valence band has only d-states. This results in the dissimilar parity of the photoexcited e^--h^+ pair in ZnO, leading to a low recombination probability, as in TiO_2. Thus, ZnO and TiO_2 are the only two among the 3d transition metal-oxide semiconductor series that remain stable upon photoexcitation [3]. It is also reported in the literature that ZnO powder has significantly larger quantum efficiency than that of TiO_2 powder [1]. This motivates us to investigate optical efficiency characteristics of ZnO.

To this end, many research studies about ZnO in aqueous solutions have been conducted. However, little research is available for ZnO and its photocatalytic efficiencies when ZnO nanparticles are embedded and immobilized in thin films (although immobilized form is comparatively more versatile in industrial applications). In this work, we thus work on the optical efficiency characterization of ZnO nanoparticles integrated in resin and report on very high spectral efficiencies for such ZnO nanoparticle films for the first time.

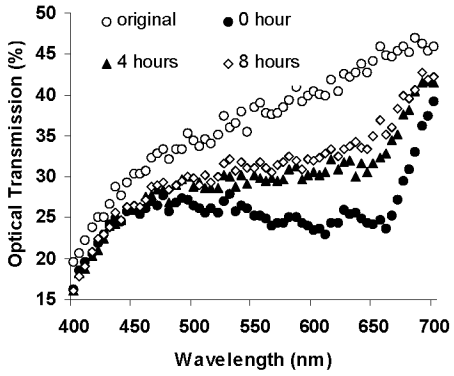

Fig. 1. Optical transmission spectra of our zinc oxide nanoparticles film right before (original) and after (0 hour) it is contaminated with methylene blue, and subsequently when optically activated for 4 and 8 hours at 290 nm. With optical activation in UV, the initial contamination is recovered by 70%.

We use ZnO particles of 100 nm in size. We chemically integrate and disperse these ZnO nanoparticles into host PVAc (poly(vinylacetate)/ poly(methylmethacrylate)) resin. We form thin films of the resulting ZnO nanocomposite by spraying. We contaminate our samples with the standard metylene blue for optical characterization. We optically activate at certain wavelengths in the UV (from 370 nm to 290 nm) and perform optical transmission spectroscopy in the visible (between 450 nm and 700 nm). During the optical activation process, we observe visual changes in the color of our samples. Figure 1 shows typical optical transmission spectra through our ZnO nanoparticle film with no contamination (original) and with the contamination but no optical activation (0 hour). Due to the contamination, there is a significant drop in the optical transmission. However, with the optical activation (for 4 hours and 8 hours with an optical power of 120 μW at a wavelength of 290 nm), the ZnO nanoparticle film recovers its optical transmission back up by 70% at the end of 8 hours. This optical recovery is attributed mostly to the photocatalytic activity of ZnO nanoparticiples. The degradation of the host resin may also in part contribute to the optical recovery of the transmission.

For a complete study of optical spectral efficiency characterization, we study the changes in the optical transmission of ZnO nanoparticles in the visible spectra as we change the excitation wavelength in the UV. We use a measure of optical efficiency to evaluate and compare the photocatalytic activity under UV exposure at different wavelengths. We extract the optical efficiency from the spectral area between the optical transmission curves of the sample before and after optical activation normalized with respect to the spectral area between the transmission curves before and after contamination across a wide spectral region (in the visible between 450 nm and 700 nm), over which the effect of the contamination and decontamination is observed. Figure 2 shows the optical efficiencies of our ZnO nanoparticles for excitation wavelengths between 290 nm and 370 nm as a function of incident total optical energy per unit area (between 1.8 Joules/cm^2 and 7.6 Joules/cm^2). We demonstrate that optical efficiencies increase with decreasing excitation wavelengths. We obtain high optical efficiency up to 70% at 290 nm shown in Fig. 2.

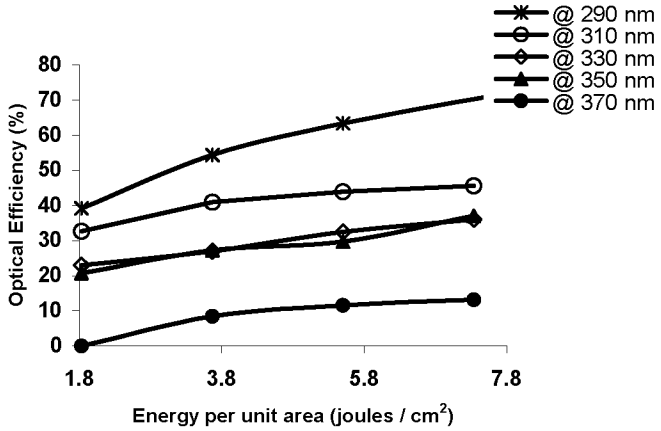

Fig. 2. Optical efficiency of our zinc oxide nanoparticles at different activation wavelengths between 290 nm and 370 nm as a function of incident total optical energies per unit area.

In conclusion, we developed and investigated photocatalytic ZnO nanoparticles integrated in thin films for optically induced decontamination and characterized their optical spectral efficiency at excitation wavelengths from 290 nm to 370 nm. We experimentally demonstrated that optical efficiencies increase with decreasing excitation wavelength. We obtained the highest optical efficiency of 70% at 290 nm. We are currently working on the development of ZnO nanoparticles embedded in other resins to further study and identify optically induced degradation mechanisms.

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